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ORIGINAL ARTICLE

Examining interaction among supplier selection strategies in an outsourcing environment using ISM and fuzzy logic approach

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Abstract Supplier selection in an outsourcing environment is a challenging task as it depends upon various dimensions. To this effect, the study presents a hybrid approach in which in the first phase, various supplier selection dimensions are identified and the structural relationship among them is modelled by applying interpretive structural modelling (ISM) approach. In phase two, the driver-dependence power of various dimensions is analysed using the MICMAC approach. From the results, it is observed that owing to high dependence power dimensions “Cost,” “Quality”, and “Service” dimensions are important from the customer’s point of view for supplier selection. So, in order to help the managers to address the risk associated with these dimensions, qualitative analysis based on fuzzy set theory has been carried out by considering three potential suppliers. The simulation experiments conducted with different combinations of “Cost,” “Quality”, and “Service” dimensions show that the supplier selection process is a tedious task and may vary with the organizational needs. The approach proposed in the study can be adopted by the supply chain professionals to address supplier selection problems.

Keywords Supply chain management · Supplier selection · Structural model · Risk analysis

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1 Introduction

A supply chain is a network of various entities such as suppliers, manufacturers, wholesalers, retailers, who coordinate with each other, to make, and sell a product or service. Collaboration with suppliers at low operational risk can possibly reduce the chances of losses or disruptions among the entities. The supplier acts as a starting point for any supply chain. Therefore, it becomes important for any supply chain to consciously make supplier selection as it is one of the key activities required for implementing a robust supply chain management (Claudia et al. 2016; Mohammed et al. 2018; Verdecho et al. 2020; Fallahpour et al. 2021; Rezaei et al. 2021). Its main aim is to identify the best suppliers and undertake resource allocation decisions for procurement of goods from them.

Moreover, procurement function is considered as one of the key function for companies because the costs associated with it accounts for more than 50% of all internal costs (Yazdani et al. 2016). Also, the supplier selection can be either single sourcing or dual (multiple) sourcing. In single sourcing, organisations rely on one supplier to fulfil their demand, and decision-maker has to decide about the superior supplier. In dual or multi-sourcing, as single supplier cannot fulfil all the company’s demands, multiple suppliers need to be selected. Thus, supplier selection problem is a multi-faceted, multi-criteria decision-making activity since different and conflicting criterions are required to be considered and assessed for selection of suppliers (Luthra et al. 2017; Taherdoost and Brard 2019; Aouadni et al. 2019a, b; Chan and Kumar 2007; Dickson 1966).

Traditionally, supplier selection is based on the ability of the supplier to meet the quality requirements, on-time deliveries, and pricing strategies. However, today the selection has become challenging because organizations today select sustainable suppliers who consider economic, green, and social aspects (Azadeh et al. 2017; Saroha et al. 2021). In principle, organisations carry the supplier assessment based on various criterions. The supplier evaluation and assessment process has changed remarkably in past few years with the use of information technology and computers. The literature review reveals that various methodologies have been used for supplier selection and evaluation such as multi criteria decision-making methods (MCDM), mathematical programming and artificial intelligence techniques (Aouadni et al. 2019a, b). Several multi-criteria methods have been adopted by the researchers for supplier selection (Muralidharan et al. 2002; Shyur and Shih 2006; Omurca, 2013; You et al. 2015; Yazdani et al. 2016; Luthra et al. 2017; Mohammed et al. 2018; Kannusamy, and Thangavelu 2019; Fallahpour et al. 2021). The mathematical models are applications of linear programming, binary integer linear programming, mixed-integer nonlinear programming, dynamic programming, stochastic programming and other quantitative approaches (Che and Wang 2008; Choudhary and Shankar 2013; Guoand Li 2014; Adeinat and Ventura 2015; Pazhaniet al. 2016; Ghaniabadi and Mazinani 2017; Govindan et al. 2020). Owing to their complexity, the application of mathematical models has not received much attention in service industries and other sectors. On the other hand, MCDM methods are easy to use, and their success depends upon human judgement (Aouadni et al. 2019a, b). According to Jain et al. (2018) and Agrawal and Kant (2020) fuzzy based approaches could be effective and handle the element of uncertainty or subjective judgements more accurately than the existing approaches used to address supplier selection problems.

In literature, researchers have made substantial efforts to develop various frameworks/ models for selecting the suppliers based on different criterions (Srinivasan et al. 2011; Luthra et al.2017; Taherdoost and Brard 2019; Fallahpour et al. 2021; Rezaei et al. 2021). However still, there is a need to develop a sound supplier selection and assessment model. Such a model is supposed to be based upon various dimensions critical to supplier section. Further, these dimensions are required to be checked for structural dependences among them so that managers can understand the existence of complex relationships between them. Before proposing any framework or model, it is essential to realize the importance of each dimension and its role in the supplier selection process. It is also required to examine the importance and relationships of dimensions among themselves. To this effect the present study aims to identify, analyze and model various dimensions which may affect the supplier selection process. The study uses ISM based methodology for understanding the interactions among various dimensions followed by driver-dependence power analysis.

The major contributions of this work are:

- Identification of the various dimensions related to supplier selection in an outsourcing environment
- Modelling the association among the dimensions and to identify potential driver dimensions
- To build a fuzzy-based inference system that helps to analyze the effect of driver dimensions on the supplier selection.

2 Literature review

Table 1 summarises the work done by various researchers on supplier selection issues.

3 Research questions and methodology

The main research questions addressed in this work are:

RQ1 What are the various dimensions associated with supplier selection in outsourcing environment?
RQ2 How these dimensions structurally interact with each other?
RQ3 What is the degree of dependence among various dimensions which affect supplier selection decisions in outsourcing environment?
RQ4 How the key dependent dimensions can be modelled to address the uncertainties associated with supplier selection problem?

The above-stated questions are answered by developing a research framework (Fig. 1) consisting of two phases. In the first phase, various dimensions associated with supplier selection in an outsourcing environment have been identified with the help of careful examination of literature and discussion with experts. ISM method is then used to model the structural association among these dimensions. The justification for use of ISM method to prioritize and analyze the association among supplier dimensions is based on its comparison with contemporary modelling techniques i.e. ANP and AHP as shown in the Table 2 (Thakkar et al. 2008). Owing to the exceptional features of ISM over AHP and ANP, authors preferred to use the ISM approach in their work. Also, in literature, the application of the ISM approach has been found to address multifaceted engineering problems, supply chain and vendor management problems, software project activities (Pfohl 2011; Rane and Kirkire, 2017; Sindhwani and Malhotra 2017; Kumar et al. 2019; Biswal et al. 2019; Sharma and Sangal 2019, Wankhade, and Kundu, 2020; Hughes et al. 2020). In the

Table 1 Summary of literature studies

S. no	Author/year	Work done	Research gap/limitations
1	Agrawal and Kant (2020)	Discussed a case study on supplier selection using Fuzzy-AHP method using conflicting criteria	For further study, other MCDM methods can be used for supplier selection problem to validate the results
2	Ayag and Samanlioglu (2016)	An approach to supplier selection problem using fuzzy ANP has been proposed	The approach lacks ability for capturing the dynamic complexity
3	Azadeh et al. (2017)	Developed model for supplier selection considering uncertainty using fuzzy DEA method	Study results needs to be validated by developing non-linear mathematical models
4	Carrera and Mayorga (2008)	The work provides an application of fuzzy logic to select suppliers in new product development	Industry-specific models which integrate supplier selection dimensions for new product development can be proposed
5	Deshmukh and Chaudhari (2011)	Supplier selection methods are summarized	They stressed upon linking supply chain performance measurement with supplier selection approaches
6	Eydi and Fazli (2019)	Developed hybrid methodology for evaluation of prospective suppliers	Work lacks investigation of association among key decision variables which impact supplier selection
7	Fallahpour et al. (2021)	Authors provided an integrated MCDM model for determining the most appropriate supplier	Lacks investigation with respect to dependence relationships among attributes
8	Jain et al. (2018)	Authors used fuzzy AHP and TOPSIS method for supplier selection by developing a case study	More dimensions for supplier selection should be taken for further investigation
9	Kumar Kar et al. (2014)	The authors explored the importance of different supplier selection criteria by conducting a Delphi study	Supplier selection criteria can be examined using a multi-industry approach
10	Govindan et al. (2020)	The authors developed multi-objective mixed-integer linear programming model for circular supplier selection	The model's efficacy can be generalized by studying the effect of various failure events related to delivery, cost, quality and flexibility
11	Li and Zeng, (2016)	Author's used failure modes and effects analysis to study supplier selection problem	The work can be extended to analyse the supplier selection dimensions in an outsourcing environment
12	Mishra et al. (2018)	Used ANP method to conduct performance evaluation of just in time supported supply chain	The interdependence of various supplier selection dimensions can further be examined using ISM approach
13	Naqvi and Amin (2021)	Conducted a detailed literature study with focus on supplier selection	More case studies can be considered to handle supplier selection problems using fuzzy methods
14	Omurca (2013)	Presented architecture for supplier selection problems to address the supplier selection	Lacks discussion on association among various supplier selection attributes
15	Pfohl et al. (2010)	Authors performed structural analysis of potential supply chain risks by using ISM approach	More risks can be identified and analysed which may affect supplier selection process
16	Paul (2015)	Author considered numerous selection criteria for managing risks associated with supply chain	The proposed model can be tested and validated by conducting a case study
17	Pang and Bai (2013)	Worked on supplier selection problem using ANP and fuzzy synthetic evaluation approach	A hierarchal model considering these attributes can be built to study the association among them
18	Rezaei et al. (2021)	Proposed a framework for supplier selection and order allocation by considering the risk reduction strategies	Work can be extended by incorporating dimensions related to cost, quality, and service levels for supplier selection
19	Wankhade, and Kundu (2020)	Authors used ISM approach to model the enablers for achieving SC agility	Work can be extended using additional dimensions for supplier selection problem
20	Taherdoost and Brard (2019)	The work provides a review of various criteria for the evaluation of suppliers	They stressed upon development of hybrid methods to address supplier selection problem
21	Simic et al. (2015)	Authors developed hybrid model for supplier assessment and selection, using genetic algorithm and harmony search algorithm	Future work can be directed towards consideration of technical, legal, geographical and commercial dimensions for performance
22	Sarkar et al. (2018)	The work proposed a new integrated method combining various tools for supplier selection under the fuzzy settings	Work can be extended by identification of additional dimensions for supplier selection problem
23	Soderberg et al. (2017)	Provided guidelines for selecting the right supplier for outsourcing of maintenance requirements	Future work can explore issues related with quality, cost and delivery of maintenance spares

Table 1 continued

S. no	Author/year	Work done	Research gap/limitations
24	Saroha et al. (2021)	Authors presented indicators for circular SC using modified BSC	The relationship among indicators can be worked out to solve the SC disruptions

Fig. 1 Research framework

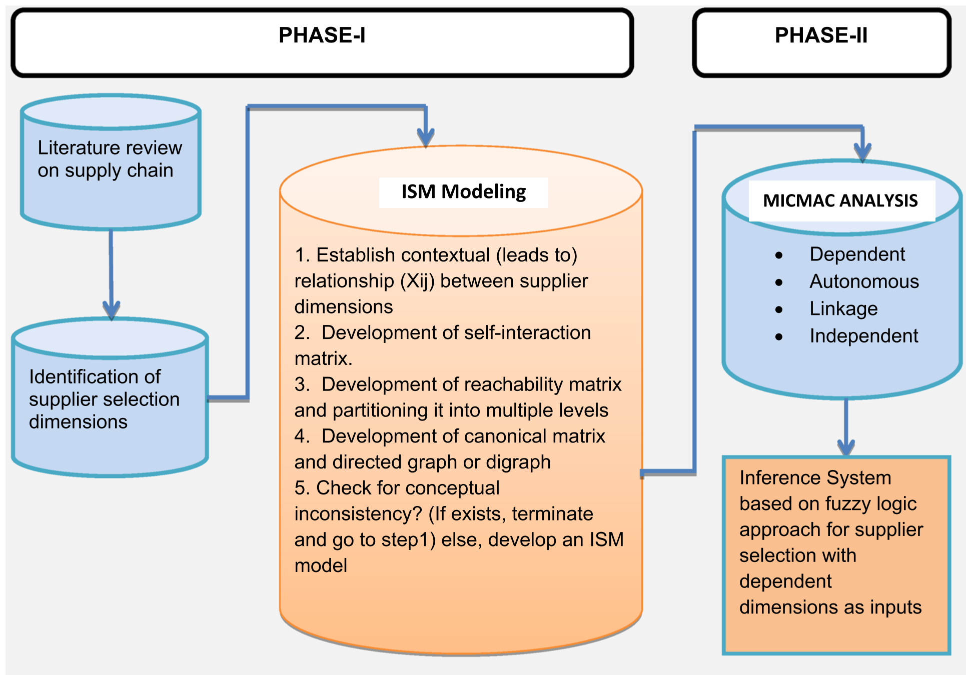


Table 2 Comparison among research methods

AHP	ANP	ISM
In AHP the hierarchy of discipline has to be strictly monitored	It is used to handle loose networks	It includes a set of interrelated criterions
It assumes functional independence of upper part of hierarchy with its lower part	It takes into account the interdependencies and non-linear relations	It creates ''leads to'' interactions among criterions
It does not deal with complex real-life situation	It is used to deal real- life non-linear situations	It successfully captures the real-life complications
It possess moderate ability to handle dynamic complexity	It possess lower ability to handle the dynamic complexity	It possess higher ability to handle the dynamic complexity

Source: Thakkar et al. (2008)

second phase, MICMAC analysis is carried out to study the effect of dimensions by developing the hierarchies based on driver and dependence power. It portrays dimensions under various clusters i.e. dependent, independent, linkage, and autonomous. Lastly, an inference system based on fuzzy logic has been built to examine the influence of dependent dimensions on supplier selection.

3.1 Supplier selection dimensions

After critical scrutiny of literature studies as discussed in Table 1, the following dimensions have been identified for supplier selection in an outsourcing environment.

1. *Quality:* It is stated as the ability of supplier to meet quality specifications constantly. It includes sub-dimensions related to accuracy, reliability, performance etc.
2. *Delivery rate/ Service:* It is defined as the ability of the supplier to adhere delivery timelines.
3. *Production capacity:* It is related to suppliers' infrastructure related to production facility, its capacity, and overall exploitation.
4. *Price:* It is defined as net price of the product after discounts.
5. *Economical Environment:* It shows the supplier's financial health in terms of liquidity ratio, solvency position, and credit rating policy.
6. *Technological level:* It is defined as presence of adequate manpower and the state of technological know-how.
7. *Management and organization:* It refers to the supplier's management, its organization to coordinate and utilize resources effectively and efficiently to meet organisational goals.
8. *Transportation and communications:* It is related to geographical location of the supplier and the presence of communication channels.
9. *Trust:* Supplier trust is the purchaser's trust in the supplier's ability to accomplish the task.
10. *Labour relations*: It refers to the nature of labour relations and conflict management practises in the company
11. *Agility:* It is the ability of an organization to respond to change and rapidly adapt to market and environmental changes in useful and cost-effective manner.
12. *Risk management:* It means reducing vulnerability and ensuring continuity in supplies.

3.2 Model development

ISM approach is based on utilizing domain expert's knowledge to disintegrate a complex system into numerous subsystems and build a hierarchal system model that portrays inter-relationships among subsystems. The method involves the following steps:

1. Listing of factors/dimensions which may affect the system.
2. Assigning the contextual association among the factors/dimensions listed out in the first step. Following terminology is used for developing the contextual relationship.
   a. V: it is used to denote the influence of dimension i on dimension j.
   b. A: it is used to denote the influence of dimension j on dimension i
   c. X: it is used to denote the influence when i and j will lead to each other
   d. O: it is used to denote when dimension i and j will not lead to each other
3. Development of structural self-interaction matrix (SSIM) for factors/dimensions, to demonstrate pair wise association between them.
4. Development of Reachability matrix from the SSIM matrix and examining it for transitivity, which is further, partitioned into different levels, as iterations proceeds.
5. Making di-graph and eliminating the transitive links among dimensions.
6. Developing the ISM model from the digraph and replacement of nodes with words.

3.2.1 Structural self interaction matrix (SSIM)

A contextual relationship of "leads to" type is chosen for analyzing the dimensions for supplier selection in an outsourcing environment. This means that one dimension helps to improve another dimension. It is on this premise; a contextual association among the dimensions is established. The terminology discussed in step 2 above is used to develop the contextual association between the supplier selection dimensions (i & j). The details of the SSIM matrix are presented in Table 3.

3.2.2 Reachability matrix

The matrix representing contextual association is converted into a 0–1 matrix called the reachability matrix obtained by substituting V, A, X, O with either 0 or 1. Afterward it is checked for transitivity.

Table 3 Matrix representing contextual association

	Dimensions										
Dimensions	12	11	10	9	8	7	6	5	4	3	2
1 Quality	O	O	A	O	O	A	A	O	V	A	O
2 Delivery rate/Service	O	A	A	A	A	A	O	O	O	A	
3 Production capacity	O	A	O	V	O	O	O	O	V		
4 Price	O	O	O	A	A	O	O	O			
5 Economical Environment	O	V	O	V	O	O	O				
6 Technological level	X	V	O	V	O	O					
7 Management and organization	V	O	V	V	O						
8 Transportation and communications	O	O	O	V							
9 Trust	V	V	A								
10 Labour relations	O	O									
11 Agility	A										
12 Risk management											

Rules for obtaining reachability matrix.

- If (i, j) is written as V in the self-interaction matrix, then in the reachability matrix (i, j) entry becomes 1, and the (j, i) entry are made 0.
- If (i, j) is written as A in the self-interaction matrix, then in the reachability matrix the (i, j) entry becomes 0, and the (j, i) entry are made 1.
- If (i, j) is written as X in the self-interaction matrix then in the reachability matrix both the (i, j) and (j, i) entries are made 1.
- If (i, j) is written as O in the self-interaction matrix, then in the reachability matrix both the (i, j) and (j, i) entries are made 0.

Thus, the final reachability matrix is refined using the transitivity rule, which is stated as if "A" is linked to "B" and "B" is linked to "C", then as a consequence, "A" is linked to "C".

Following these rules, the reachability matrix is obtained, as shown in Table 4.

The transitive elements in the final reachability matrix are shown by 1*.After including the transitivity links, we obtained the final reachability matrix (Table 5).

3.2.3 Level partition

Once the reachability matrix is formed, two sets i.e. reachability and antecedent sets are obtained. The reachability set contains dimension i and other dimensions which drive or influence it. Similarly, the antecedent set contains dimension i and other dimensions which drive or influence it. Subsequently, the intersection set is obtained which contains common dimensions of both reachability and antecedent sets. Those dimensions in which reachability and intersection set are similar, they are given the highest precedence relationship in the structural model, and consequently that dimension is detached from the remaining sets. The procedure of awarding precedence relationship is continued until all the levels are ascertained. It took five iterations to complete the process in the present case, as presented in Table 6.

3.2.3.1 Lower triangular matrix A lower triangular matrix is obtained by arranging the various dimensions at the similar level across rows and columns of the final reachability matrix. Table 7 presents the lower triangular matrix.

3.2.4 Formation of diagraph and ISM

Dimensions in the diagraph are placed according to the levels obtained during the iterations. As shown in Table 6, for the problem, it took a total of five iterations to complete the process.

The dimensions found in the iteration-I are placed at the uppermost position in the hierarchy and the dimensions found in the iteration-II are placed at the subsequent level and the procedure is repeated until all the dimensions so obtained in different iterations are positioned in the hierarchal model. Figure 2 presents the ISM for supplier selection with five levels.

4 Phase-II MICMAC analysis and fuzzy logic

4.1 MICMAC analysis

To answer RQ3 i.e., the influencing dynamics of various supplier selection dimensions in outsourcing environment MICMAC (cross-impact matrix multiplication applied to classification) analysis has been performed. The method is based on the multiplication properties of matrices (Mandal

Table 4 Reachability matrix

Dimensions	Dimensions											
	1	2	3	4	5	6	7	8	9	10	11	12
1. Quality	1	0	0	1	0	0	0	0	0	0	0	0
2. Delivery rate/Service	0	1	0	0	0	0	0	0	0	0	0	0
3. Production capacity	1	1	1	1	0	0	0	0	1	0	0	0
4. Price	0	0	0	1	0	0	0	0	0	0	0	0
5. Economical environment	0	0	0	0	1	0	0	0	1	0	1	0
6. Technological level	1	0	0	0	0	1	0	0	1	0	1	1
7. Management and organization	1	1	0	0	0	0	1	0	1	1	0	1
8. Transportation and communications	0	1	0	1	0	0	0	1	1	0	0	0
9. Trust	0	1	0	1	0	0	0	0	1	0	1	1
10. Labour relations	1	1	0	0	0	0	0	0	1	1	0	0
11. Agility	0	1	1	0	0	0	0	0	0	0	1	0
12. Risk management	0	0	0	0	0	1	0	0	0	0	1	1

Table 5 Final reachability matrix

	Criterion												Driving power
Criterion	1	2	3	4	5	6	7	8	9	10	11	12	
1. Quality	1	0	0	1	0	0	0	0	0	0	0	0	2
2. Delivery rate/service	0	1	0	0	0	0	0	0	0	0	0	0	1
3. Production capacity	1	1	1	1	0	1*	0	0	1	0	1*	1*	8
4. Price	0	0	0	1	0	0	0	0	0	0	0	0	1
5. Economical environment	1*	1*	1*	1*	1	1*	0	0	1	0	1	1*	9
6. Technological level	1	1*	1*	1*	0	1	0	0	1	0	1	1	8
7. Management and organization	1	1	1*	1*	0	1*	1	0	1	1	1*	1	10
8. Transportation and communications	1*	1	1*	1	0	1*	0	1	1	0	1*	1*	9
9. Trust	1*	1	1*	1	0	1*	0	0	1	0	1	1	8
10. Labour relations	1	1	1*	1*	0	1*	0	0	1	1	1*	1	9
11. Agility	1*	1	1	1*	0	1*	0	0	1*	0	1	1*	8
12. Risk management	1*	1*	1*	1*	0	1	0	0	1*	0	1	1	8
Dependence power	10	10	9	11	1	9	1	1	9	2	9	9	

and Deshmukh 1994) and divides the various dimensions into four categories as dependent, independent, influential, and autonomous dimensions (Biswal et al. 2019; Wankhade and Kundu 2020).

The dependence and the driving powers of all the supplier dimensions considered in the study are presented in Table 5 Sect. 3.2.2. From the table, it is observed that rows with entries of ‘1’ are used to indicate the driving power and column entries are used to indicate the dependence power of the dimensions. Using this information, the MICMAC matrix diagram is made, as depicted by Fig. 3. As an illustration, it can be inferred from Table 5 that dimension number 7 i.e. management and organization has a score of 10 under driving power of 10 and has a score of 1 under dependence power. Hence, based on the scores the dimension 7 is placed in quadrant 4 represented by independent category in the MICMAC diagram.

Further, all the supplier selection dimensions are grouped under four clusters.

- Cluster 1: In the study, no dimension figures out in the autonomous cluster, which indicates that all dimensions are important and has to be considered by the management for supplier selection in an outsourcing environment.

Table 6 Iterations

Enablers	Reachability set	Antecedent set	Intersection set	Level
Iteration 1				
1	1,4	1,3,5,6,7,8,9,10,11,12	1	
2	2	2,3,5,6,7,8,9,10,11,12	2	I
3	1,2,3,4,6,9,11,12	3,5,6,7,8,9,10,11,12	3,6,9,11,12	
4	4	1,3,4,5,6,7,8,9,10,11,12	4	I
5	1,2,3,4,5,6,9,11,12	5	5	
6	1,2,3,4,6,9,11,12	3,5,6,7,8,9,10,11,12	3,6,9,11,12	
7	1,2,3,4,6,7,9,10,11,12	7	7	
8	1,2,3,4,6,8,9,11,12	8	8	
9	1,2,3,4,6,9,11,12	3,5,6,7,8,9,10,11,12	3,6,9,11,12	
10	1,2,3,4,6,9,10,11,12	7,10	10	
11	1,2,3,4,6,9,11,12	3,5,6,7,8,9,10,11,12	3,6,9,11,12	
12	1,2,3,4,6,9,11,12	3,5,6,7,8,9,10,11,12	3,6,9,11,12	
Iteration 2				
1	1	1,3,5,6,7,8,9,10,11,12	1	II
3	1,3,6,9,11,12	3,5,6,7,8,9,10,11,12	3,6,9,11,12	
5	1,3,5,6,9,11,12	5	5	
6	1,3,6,9,11,12	3,5,6,7,8,9,10,11,12	3,6,9,11,12	
7	1,3,6,7,9,10,11,12	7	7	
8	1,3,6,8,9,11,12	8	8	
9	1,3,6,9,11,12	3,5,6,7,8,9,10,11,12	3,6,9,11,12	
10	1,3,6,9,10,11,12	7,10	10	
11	1,3,6,9,11,12	3,5,6,7,8,9,10,11,12	3,6,9,11,12	
12	1,3,6,9,11,12	3,5,6,7,8,9,10,11,12	3,6,9,11,12	
Iteration 3				
3	3,6,9,11,12	3,5,6,7,8,9,10,11,12	3,6,9,11,12	III
5	3,5,6,9,11,12	5	5	
6	3,6,9,11,12	3,5,6,7,8,9,10,11,12	3,6,9,11,12	III
7	3,6,7,9,10,11,12	7	7	
8	3,6,8,9,11,12	8	8	
9	3,6,9,11,12	3,5,6,7,8,9,10,11,12	3,6,9,11,12	III
10	3,6,9,10,11,12	7,10	10	
11	3,6,9,11,12	3,5,6,7,8,9,10,11,12	3,6,9,11,12	III
12	3,6,9,11,12	3,5,6,7,8,9,10,11,12	3,6,9,11,12	III
Iteration 4				
5	5	5	5	IV
7	7,10	7	7	
8	8	8	8	IV
10	10	7,10	10	IV
Iteration 5				
7	7	7	7	V

- Cluster II: The three dimensions i.e. Quality, Service, and Cost dimensions fall in the dependent category. As evident from Fig. 3 these dimensions possess the least driving power and high dependence power. These are placed at the uppermost position i.e. at level1 in the ISM model.
- Cluster III: In this cluster five dimensions i.e. production facilities & capacity, trust, agility, technical capability and risk management are placed. These dimensions are called linkage dimensions as they are affected by dimensions at lower-level and as a result, they impact the left over dimensions in the hierarchical model.

Table 7 Lower triangular matrix

Dimensions	2	4	1	3	6	9	11	12	5	8	10	7
2	1	0	0	0	0	0	0	0	0	0	0	0
4	0	1	0	0	0	0	0	0	0	0	0	0
1	0	1	1	0	0	0	0	0	0	0	0	0
3	1	1	1	1	1	1	1	1	0	0	0	0
6	1	1	1	1	1	1	1	1	0	0	0	0
9	1	1	1	1	1	1	1	1	0	0	0	0
11	1	1	1	1	1	1	1	1	0	0	0	0
12	1	1	1	1	1	1	1	1	0	0	0	0
5	1	1	1	1	1	1	1	1	1	0	0	0
8	1	1	1	1	1	1	1	1	0	1	0	0
10	1	1	1	1	1	1	1	1	0	0	1	0
7	1	1	1	1	1	1	1	1	0	0	1	1

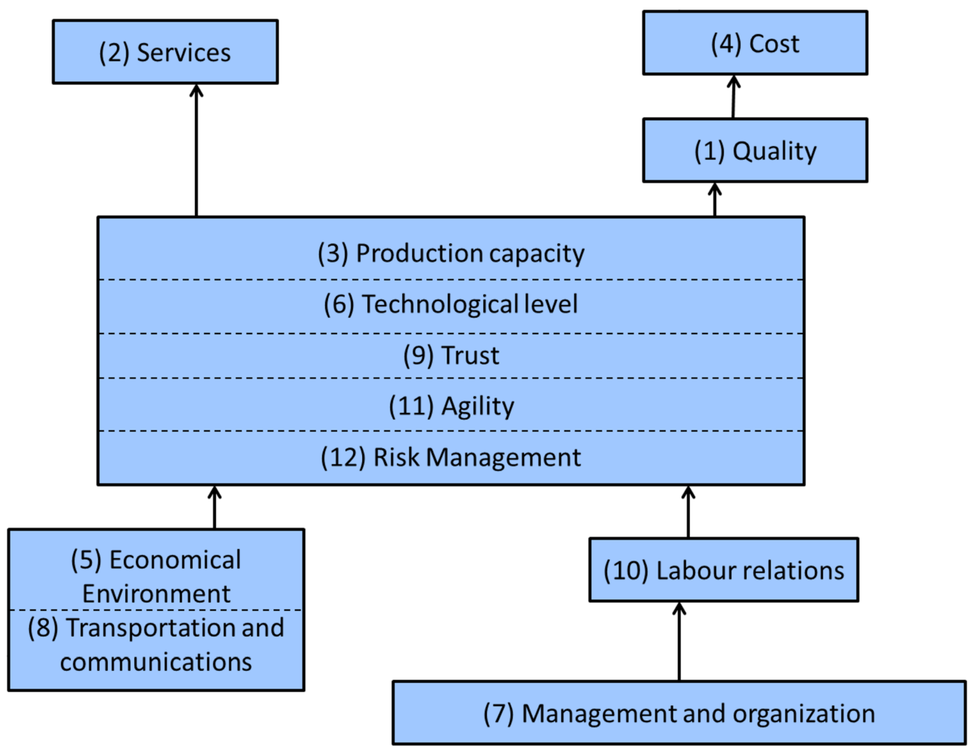


Fig. 2 Interpretive structural models for supplier selection

- Cluster IV: The dimensions like economic environment, labour relations, transportation, and management and organisation are grouped in this cluster and they are called independent dimensions.

4.2 Fuzzy logic

To answer RQ4 an inference system based on fuzzy logic has been build. The basic structure of the proposed system is presented in Fig. 4.

The key components of the system are.

- Fuzzification: This process in fuzzy system is used to relate the numerical value of the input dimensions to the values on the linguistic scale.

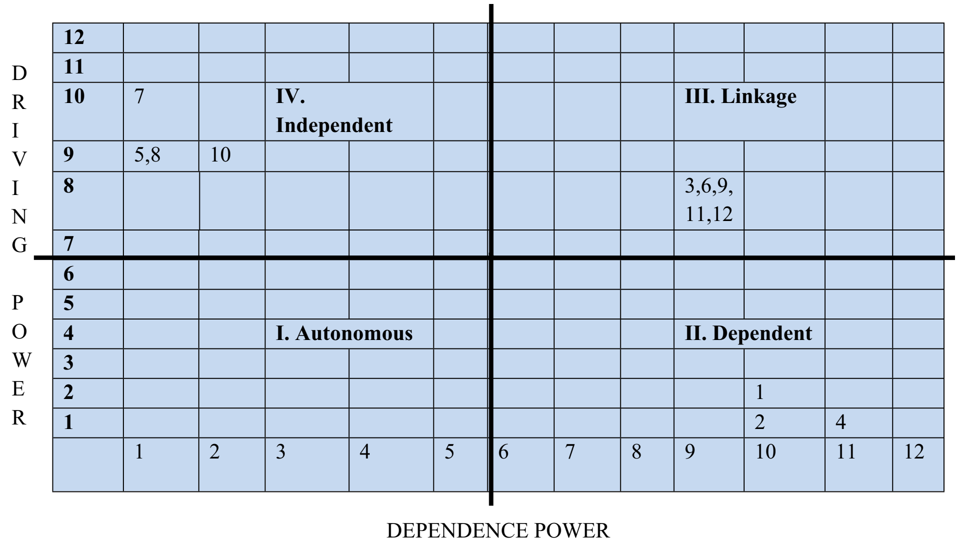


Fig. 3 Driving power and dependence diagram

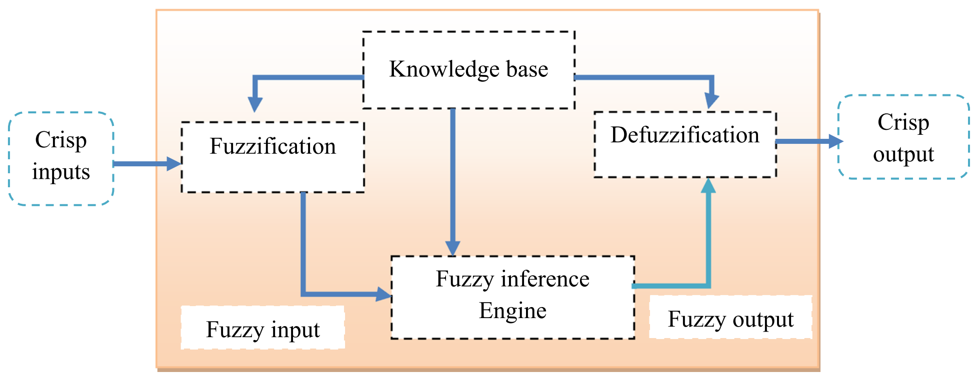


Fig. 4 Fuzzy inference system

- Fuzzy (If–Then) rules: After completing fuzzification, if–then rules are generated. These rules express and model the domain expert's knowledge in if–then format. The rule base is formed by obtaining knowledge collected from professional experts, databanks, and previous literature on the subject (Xie et al. 1999, Ross 2009). For instance, fuzzy rule is composed as: *If M is Ai, THEN N is Bi*
- Fuzzy inference system: Being a main unit of fuzzy logic system it is used to interpret the values in the input vector and, on the basis of some sets of rules, it assigns the values to the output vector. Two most common types of inference systems widely used are: Mamdani-type and Sugeno-type.
- Defuzzification: It is defined as the process of converting a fuzzy number into a precise or single value. Various forms of defuzzification methods are available in literature such as center of gravity (COG), mean of maximum (MOM), and center average methods (Ross 2009).

4.2.1 Illustrative case

The notion of fuzzy logic application in the selection of prospective suppliers is discussed with the help of case study approach by considering textile, textile product, and apparel manufacturing industries. The supply chains in these industries are so intricate that it has become challenging to cope with supplier relationships effectively. Thus, selecting the genuine supplier from the very beginning is important in order to ensure that deliveries are made on right time, with right quality and desired quantity. To this effect, various dimensions are used when potential suppliers are to be evaluated. In literature, various authors paid attention to cost, quality, and service dimensions (Ghodsypour and O'Brien 1998; Braglia and Petroni 2000; Kumar et al. 2013; Kumar and Pani 2014; Taherdoost and Brard 2019; Fallahpour et al. 2021; Rezaei et al. 2021). In the study, the three dimensions, i.e., quality, service, and cost were considered as inputs to address the supplier selection problem. In business strategies, the sub-dimensions for quality include low defect rates and high process capability, similarly for service the sub-dimensions are on-

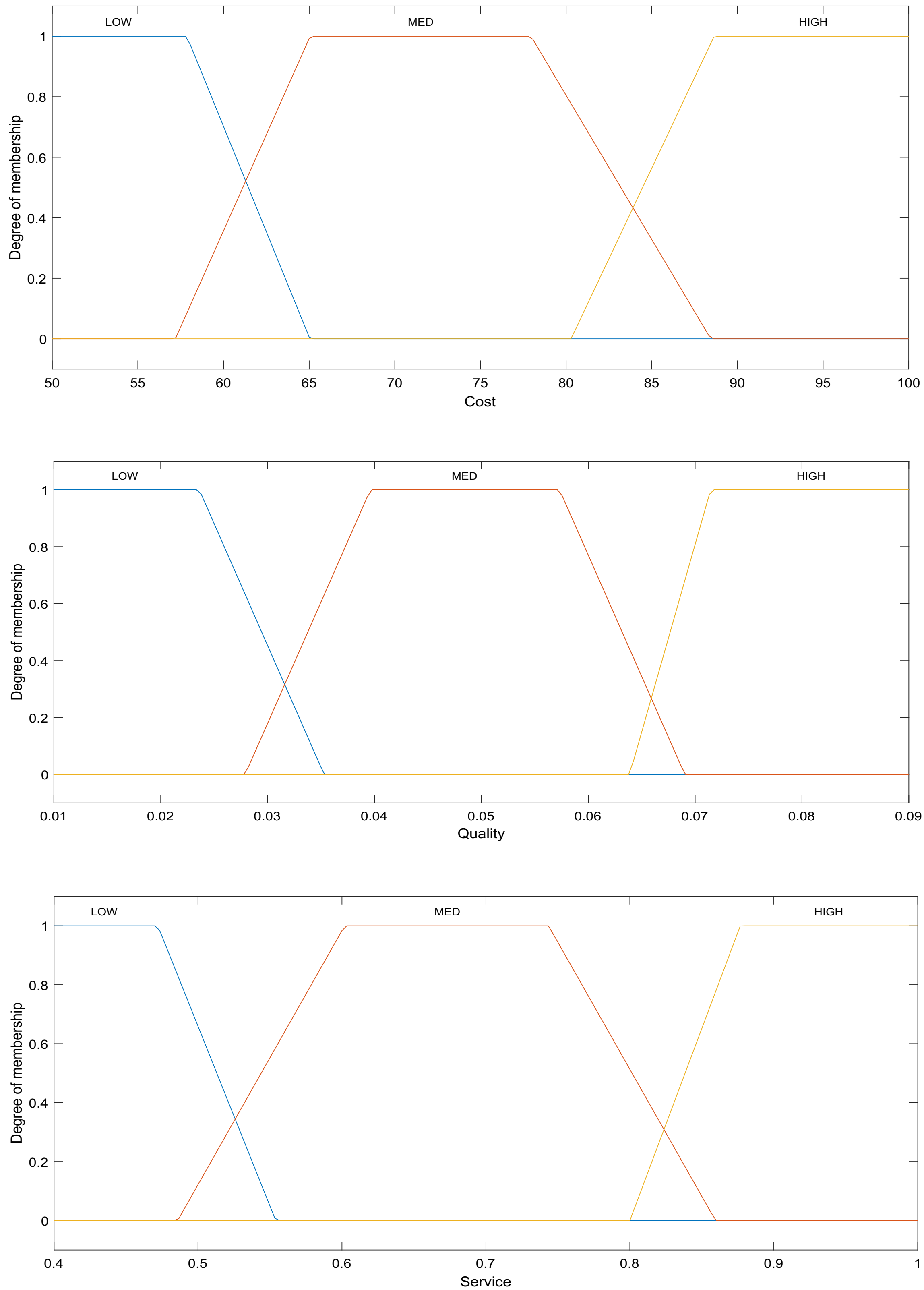


Fig. 5 Input membership functions for cost, quality, and service

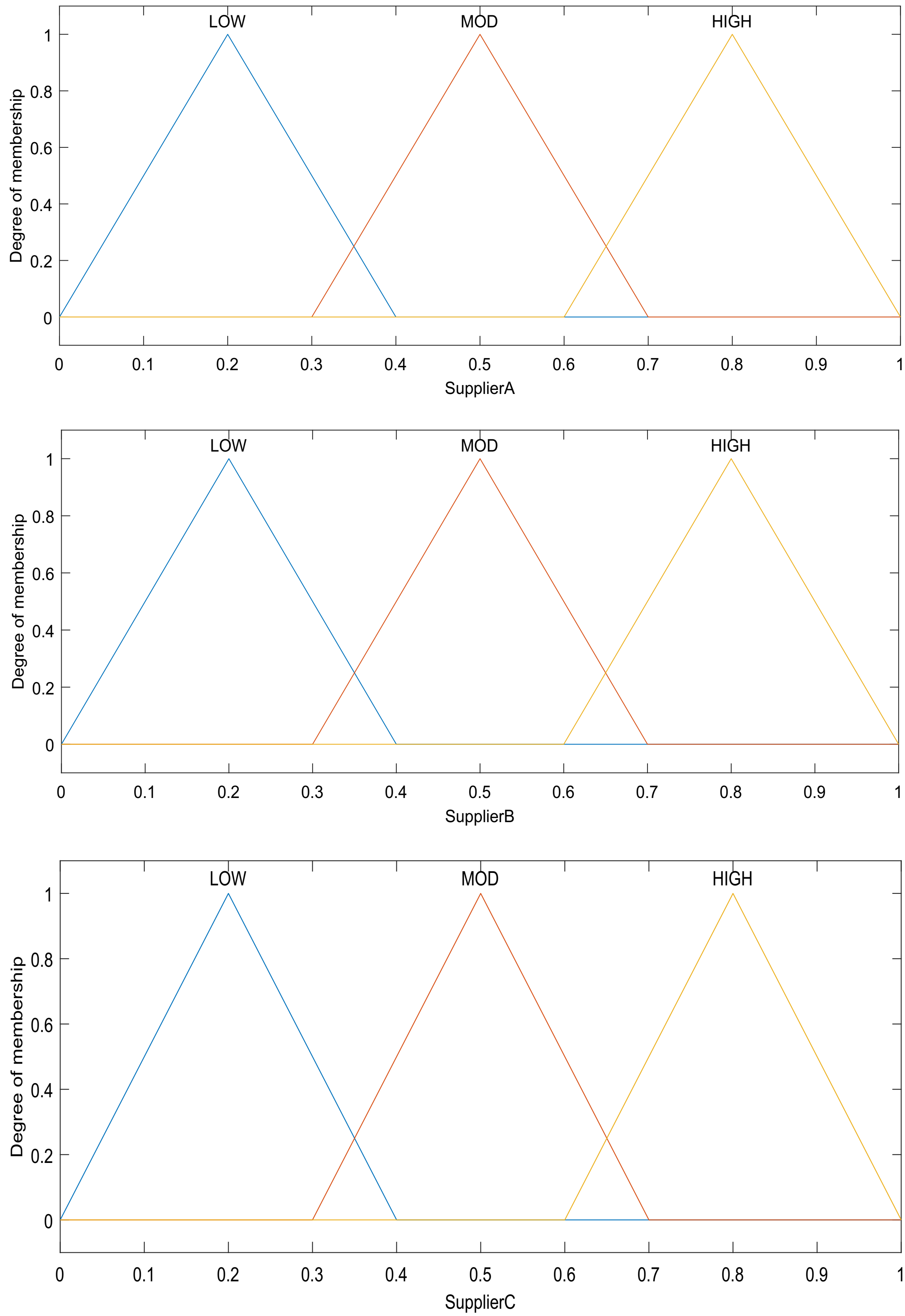


Fig. 6 Output membership functions for Supplier A, Supplier B, and Supplier C

time deliveries, quickness to respond to changes and flexible processes. For cost, various sub-dimensions are cost related to inland transportation, cost and freight price, tariff and taxes, warehouse storage etc. (Ghodsypour and Brien 1998; Sharon Ordoobadi 2009; Li and Zeng 2016). A questionnaire (shown in appendix) is designed to collect the data from the key stakeholders in textile, textile product, and apparel industries by considering the above dimensions.

The following paragraphs present the details of the proposed method.

Linguistic terms The terms low, medium, and high are used as linguistic terms to define the input dimensions, i.e., quality, cost, and time, used in the study for supplier selection.

Fuzzification In the study, the input variables are fuzzified using trapezoidal membership functions, and output membership functions for three suppliers (X, Y&Z) are fuzzified using the triangular membership function. Figure 5 presents the membership functions for inputs i.e. cost, quality, and service. Figure 6 presents output membership function plots for three suppliers (X, Y&Z). For the cost dimension, range of input is 70–100. According to Ghodsypour and O'Brien (2001), on an average in product cost the purchased materials and services represent up to 70%. For the firms dealing with high technology, the product cost for purchased materials and services constitute up to 80%. For the dimension quality, the defect rate is used to define the membership function, which ranges from 0.01 to 0.09. The range of other sub-dimension i.e. 'service level'' the range considered is between 0.4–1. The decision maker can decide any value. Three options considered in the study are: Good (0.40–0.55), better (0.50–0.85), and Best (0.8–1).

Rule base and Fuzzy inference system Based on the alternate combinations of input dimensions, the rule base is developed in this step to provide a computational mechanism in if–then form. According to Jin (2000), a fuzzy inference system may consist of numerous rules as possible in order to fill the input–output domain of the system. Conversely, it shall consist of limited number of rules because large set of rules bounds the generalization of the model. In the study, based upon the input dimensions and linguistic terms used to represent these dimensions, a total of 27 rules have been made. Figure 7 shows the rules generated in the FIS editor for the supplier selection problem.

Developed by Wang and Mende1 (1992), the inference system maps the situation –action pairs using a given set of inputs and outputs. In the study, Mamdani's method is used to map the inputs with outputs. The max–min operator used in Mamdani system is presented in Eq. (1)

$$\mu_B(y) = \min - \max(\beta_k, \mu_{B_k}(y)), \quad (1)$$

where, $\beta_k = \min \alpha_{i,k}$ [$\alpha_{i,k} = sup\ min\ (\mu_A{}' (x_i).\ \mu_{Ai,k} (x)$].

Graphically, Eq. 1 is depicted in Fig. 8. The symbols R_{11} and R_{12} signify fuzzy antecedents of Rule 1, and the symbol B_1 signifies consequent part of Rule 1. "And"

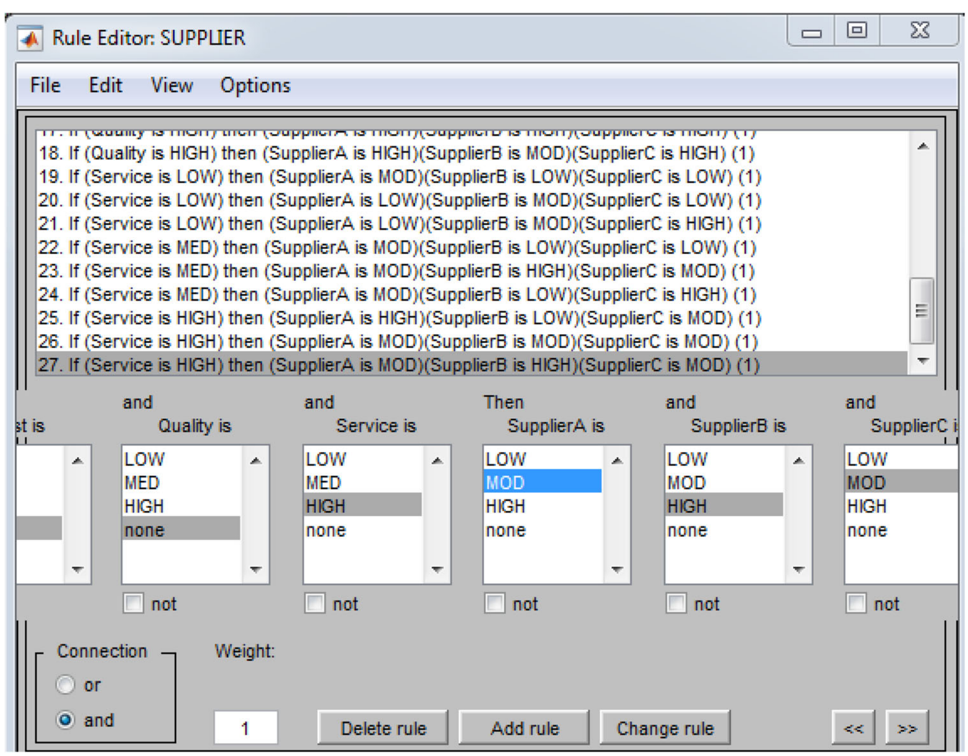


Fig. 7 Rules framed in the rule base editor

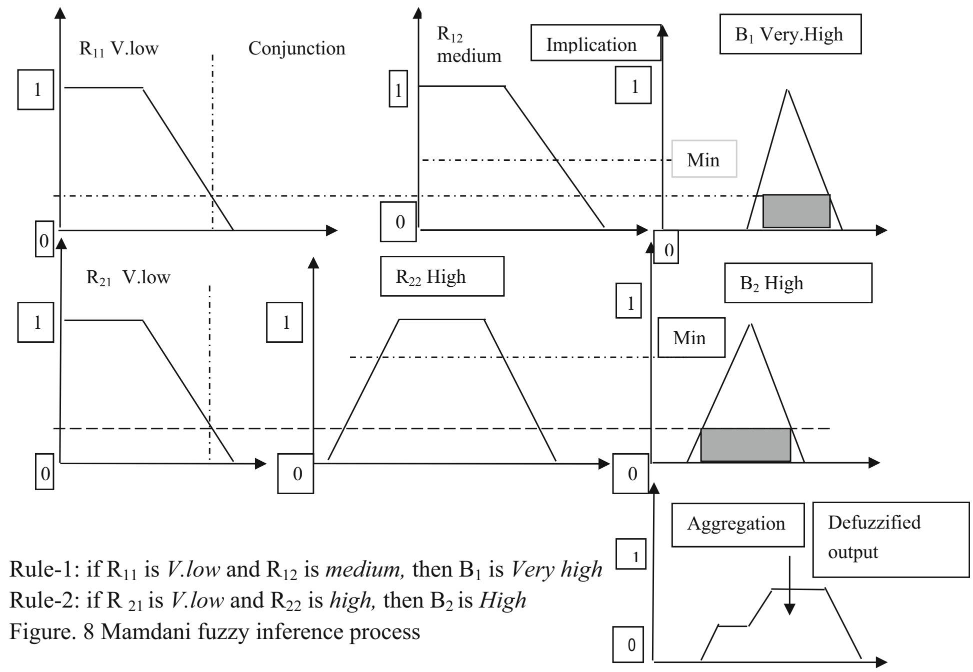


Fig. 8 Mamdani fuzzy inference process

connector is used to link the antecedent pairs in rules. The fuzzy inference process is carried out for two rules as shown in Fig. 8 respectively.

The aggregated fuzzy set is obtained by using the centroid method for defuzzification. It is represented as shown by Eq. (2).

$$y = \int y\mu\text{Aggr}(y)dy / \int \mu\text{Aggr}(y)dy \quad (2)$$

where; μAggr(y) represents the fuzzy set obtained after aggregation and the denominator ∫μAggr(y) represents the area below μAggr(y).

5 Results and discussions

As discussed in the beginning of Sect. 4.2.1, to illustrate the concept of fuzzy logic in selecting prospective suppliers, we considered textile, textile product, and apparel manufacturing industries. Data with respect to sub dimensions representing the quality, service and cost dimensions is collected from the respondents who were mainly the managers responsible for looking procurement, production, and quality control functions in their organisations. The sample questionnaire is presented in the "Appendix" which is used to get the responses. Questionnaire results were summarised, which were mainly based on the qualitative assessment on five point scale (least important-highly important). Additionally, the experience, and perception of experts on cost, quality and service dimensions forms the basis for conducting simulations under various settings.

In the first simulation experiment, the cost is considered high, quality is considered low, and service is considered high. With respect to these three input combinations, the simulation output for three suppliers so obtained are 0.502 (supplier X), 0.498 (supplier Y) and 0.583 (Supplier Z); which shows that supplier Z performs better and hence is recommended under the stated linguistic input dimensions used to select the supplier.

In the second simulation experiment the cost is considered as moderate, quality is considered as moderate, and service is considered as high. with respect to these three input combinations the simulation output for three suppliers so obtained are 0.54 (supplier X), 0.460 (supplier Y) and 0.444 (Supplier Z); which shows that supplier X performs better and hence is recommended under the stated linguistic input dimensions used to select the supplier.

In the third simulation experiment the cost is considered as high, quality is considered as low, and service is considered as moderate. With respect to these three input combinations the simulation output for three suppliers so obtained are 0.478 (supplier X), 0.522 (supplier Y) and 0.504 (Supplier Z); which shows that supplier Y performs better and is recommended under the stated linguistic input dimensions used to select the supplier.

Similar experiments can be conducted with different linguistic settings of input dimensions related to cost, quality, and service and supplier selection process based upon organizational needs can be achieved.

Table 8 presents the results of simulation experiments with input dimensions related to cost, quality and service. The values of scores obtained for Supplier X, Y and Z are

Table 8 Simulation experiments with input parameters and results

	Input		Output scores			Final recommendation
	Dimensions	Linguistic	Supplier A	Supplier B	Supplier C	Recommended supplier
Simulation 1						
	COST	High (92.6)	0.502	0.498	0.583	Supplier C
	QUALITY	Low (0.027)				
	SERVICE	High (1)				
Simulation 2						
	COST	Mod (77.1)	0.540	0.460	0.444	Supplier A
	QUALITY	Mod (0.048)				
	SERVICE	High (1)				
Simulation 3						
	COST	High (100)	0.478	0.522	0.504	Supplier B
	QUALITY	Low (0.035)				
	SERVICE	Moderate (0.744)				

also shown with final recommendation. Figure 9a–c shows the simulation outputs. Similar studies for supplier selection problem under fuzzy environment were conducted in literature by Kumar et al. (2013); Azadeh et al. (2017); Eydi and Fazli, (2019); Fallahpour et al. (2021) which signifies the importance of the present study. Thus, the approach presented in the study provides a decision making framework which enables the managers to assess the supplier performance based on key dimensions.

6 Conclusions and future scope

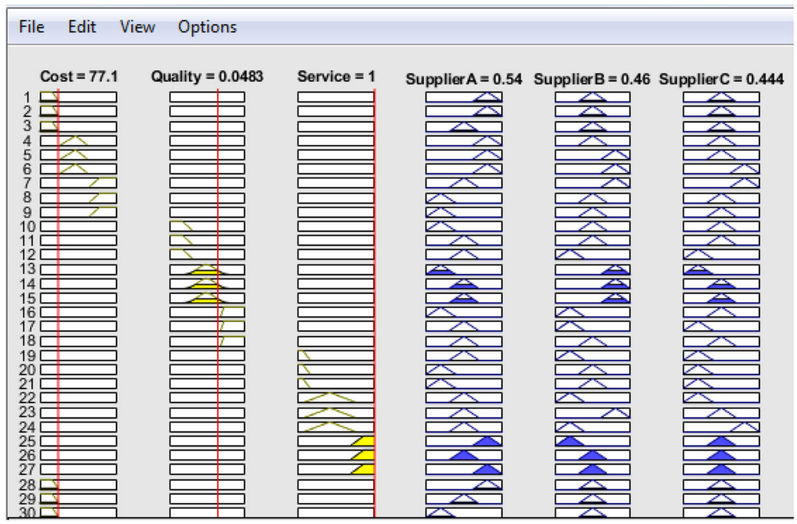
The present work provides a hybrid approach to support supply chain professionals in undertaking decisions related to identification of the key dimensions involved in supplier selection. Based upon the critical scrutiny of literature studies eleven important dimensions related to the supplier selection problem are ascertained. To define the structural relationship between these dimensions, ISM model is developed. The model portrays these dimensions at various levels. At level 1 dimension management and organization is there followed by three dimensions i.e. economic environment, labor relations and transportation and communications at Level II. All these dimensions come under independent category, which means that they possess strong dependence and least driving power. Level III comprises of five dimensions i.e., production capacity, agility, trust, technological level and risk management. These are called linkage dimensions as both driving power and dependence power are strong. Level IV consists of one dimension only i.e. quality and Level V has two dimensions i.e. delivery rate/service and cost. They figure at top of the ISM model.

In addition, a case study based on qualitative analysis has been developed by considering three prospective suppliers from textile, textile product, and apparel manufacturing industries. Data is collected from these companies on quality, service and cost dimensions on the five-point scale. Further, by developing an inference system based on fuzzy logic, the simulation experiments were conducted with different combinations of three dependent dimensions i.e., cost, quality, service and delivery to show that the supplier selection process may vary with the organization's needs. The results presented in Sect. 5 indicate the most appropriate supplier under different settings. For instance, when the cost is considered high, quality is considered low, and service is considered high than supplier Z performs better and hence is recommended.

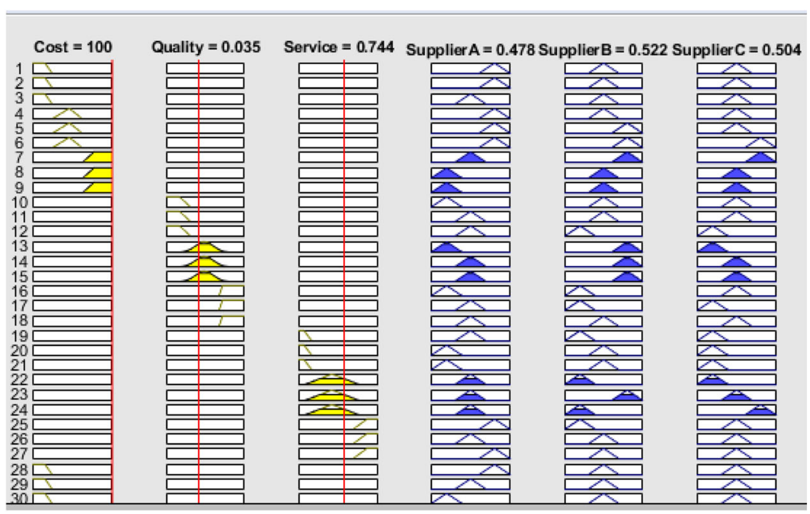
The novel approach proposed in the study is very flexible and can be adopted by managers to address the real supplier selection issues. In literature too Azadeh et al. (2017) in their study measured the effects of dimensions i.e. customer trust, cost, and delivery time simultaneously for selecting the most appropriate supplier in an auto parts manufacturer to control potential SCM disruptions. They used fuzzy data envelopment analysis to handle the problem of data subjectivity and uncertainty. Thus, present study successfully demonstrates the applicability of proposed approach for supplier selection problem. For future work more dimensions that measure supplier performance could be included in the analysis. In addition to this, future researchers should also focus on supplier development dimensions figured in quadrant IV of the driver–dependence diagram. Other modelling techniques such as

Fig. 9 a–c Simulation results

(a)



(b)



(c)

Table 9 Summary of research questions

Research questions	Discussion
RQ1: What are the various dimensions associated with supplier selection in outsourcing environment?	The various dimensions associated with supplier selection in an outsourcing environment are: Quality, Delivery rate/Service, Production capacity, Price, Economic Environment, Technological level, Management and Organization, Transportation and communications, Trust, Labour relations, Agility, Risk management
RQ2:How these dimensions structurally interact with each other?	The interaction among the supplier dimensions is exhibited with the help of ISM model (Fig. 3). All supplier dimensions are presented in a hierarchy of five different levels. It is observed that at level 1 (from bottom) dimension management and organization are there. Level II has three dimensions, i.e., economic environment, labor relations and transportation, and communications. Level III consists of five dimensions i.e. risk management, technological level, agility, trust and production capacity. At level 4 one dimension, i.e., quality is there and at level V two dimensions, delivery rate/service, and cost
RQ3. What is the degree of dependence among various dimensions which affect supplier selection decisions in outsourcing environment?	It is seen from the MICMAC diagram that quality, service, and cost fall in the dependent category. These dimensions possess less driving power and high dependence power. Five linkage dimensions are shown in quadrant III, which get influenced by dimensions below them and as a result they impact other dimensions. In cluster IV, we have dimensions with high driving power, i.e. economic environment, labor relations, transportation, management, and organization
RQ4.How the key dependent dimensions can be modelled to handle the uncertainties associated with supplier selection?	A fuzzy inference system based on key dependent variables i.e., cost, quality, and service is developed to model the uncertainties associated with supplier selection problem. An illustrative case has been developed to present the working of the proposed model. Three ssimulation experiments for the selection of suppliers are carried out. The values of scores obtained for Supplier X, Y and Z under the different linguistic combination of inputs are obtained, and the final supplier selection recommendation is made based on the maximum score. Figure 9a–c show the simulation outputs

analytical hierarchy process, fuzzy ISM/MICMAC, or structural equation modelling can be explored, and the results could be validated. Taking into account the inherent complexities involved in the supplier selection the future researchers can use risk aversion tools (failure mode effects analysis (FMEA); hazard and operability study (HAZOP), fault tree analysis (FTA) etc.) which can help the organizations to strengthen their supply chains and mitigate the possible risks in supplier selection process. Table 9 summarizes the research questions with discussions.

Appendix: Questionnaire on supplier selection dimensions

Fraction Defective/No. of Defects

	1	2	3	4	5	
Least important	○	○	○	○	○	Highly important

Process capability

	1	2	3	4	5	
Least important	○	○	○	○	○	Highly important

Transportation cost

	1	2	3	4	5	
Least important	○	○	○	○	○	Highly important

Raw material cost

	1	2	3	4	5	
Least important	○	○	○	○	○	Highly important

Warehouse/storage

	1	2	3	4	5	
Least important	○	○	○	○	○	Highly important

Tariff and taxes

	1	2	3	4	5	
Least important	○	○	○	○	○	Highly important

Response to changes/ process flexibility

	1	2	3	4	5	
Least important	○	○	○	○	○	Highly important

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Declarations

Conflict of interest No conflict of interest.

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